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# TUV II - A Towed Wet Submersible for Use in Fishing Gear Research

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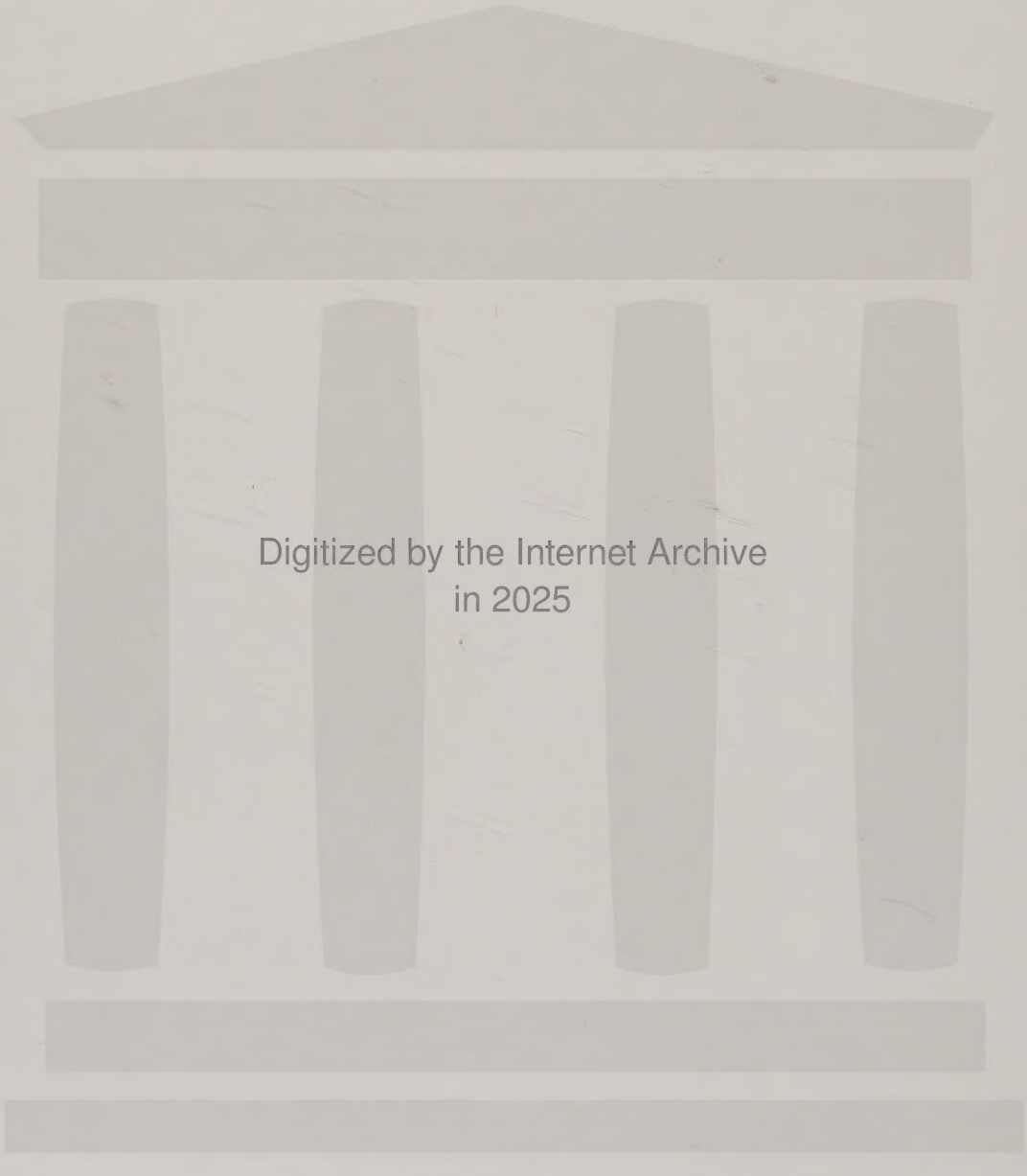

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# TUV II - A Towed Wet Submersible for Use in Fishing Gear Research

J Main and GI Sangster

**Marine Laboratory Aberdeen**

## Introduction

The first underwater cine films by Lt Cmdr J. Hodges (Anon, 1952, 1953), changed the attitudes of both fishermen and scientists to fish behaviour in relation to fishing gear and stimulated the interests of researchers in many countries. Since these historic films were made, diving has been used by scientists as a technique for directly observing fish and nets (Dickson, 1959, 1961; Parrish, Hemmings, Chapman, Main and Lythgoe, 1964; Parrish, Blaxter, Pope and Osborne, 1967; High, 1967; Hemmings, 1967a, b, 1973) or for filming fishing gears either by hanging on to the nets (Plate I) or allowing the whole gear to pass to one side of them (Main and Sangster, 1976, 1978). Gear technologists in Poland and the USSR have observed full sized trawls with some success, using a two-man, one atmosphere, water-tight towed vehicle (Anon, 1965; Korotkow, 1969; Trillo, 1976; Korotkow and Martyschewski, 1977). All these techniques have, however, their limitations regarding (a) the free-swimming diver holding a fixed position relative to the moving trawl, (b) the restricted viewing through a dry submersible porthole and (c) the eventual feedback of all the relevant information.

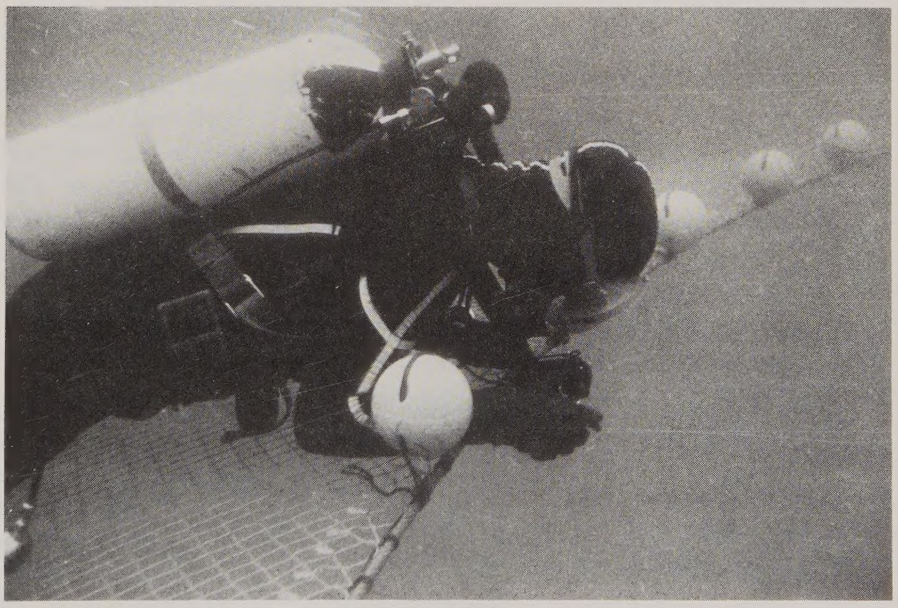


**Plate I. Free-swimming SCUBA diver with a 35 mm type camera on the headline of a trawl.**

The fish capture diving team involved in gear research and fish behaviour studies at the Marine Laboratory, Aberdeen, has completed more than 4,000 hours free-diving on full sized trawls, including Danish seine-nets and pelagic, semi-pelagic and bottom trawls (Main and Sangster, 1976, 1978). During these dives, all the relevant fish reactions and trawl gear observations were recorded by the divers using either still or cine cameras, whereas, the supplementary details of these visual observations were voice recorded using a small cassette tape recorder housed in a watertight pressure case strapped to each diver's aqualung (Hemmings, 1973; Main and Sangster, 1978). These

records from each diver were complete only if all the intended data had been successfully recorded on film and tape. The results were inevitably delayed by the transcription of the tape recordings and the film processing time. The main drawbacks were due to recorder failures and bad photographic techniques which produced incomplete or unsatisfactory results. These drawbacks were mainly overcome by the use recently of a low light underwater television camera carried by free-swimming divers (Plate II, Main and Sangster, 1976; Wardle and Priestley, 1976) but handling the camera and cable was difficult when moving around the trawl towed at speeds of 1.5-1.8 m $s^{-1}$ (3-3.5 knots) and was virtually impossible in the otterboard and bridle areas.

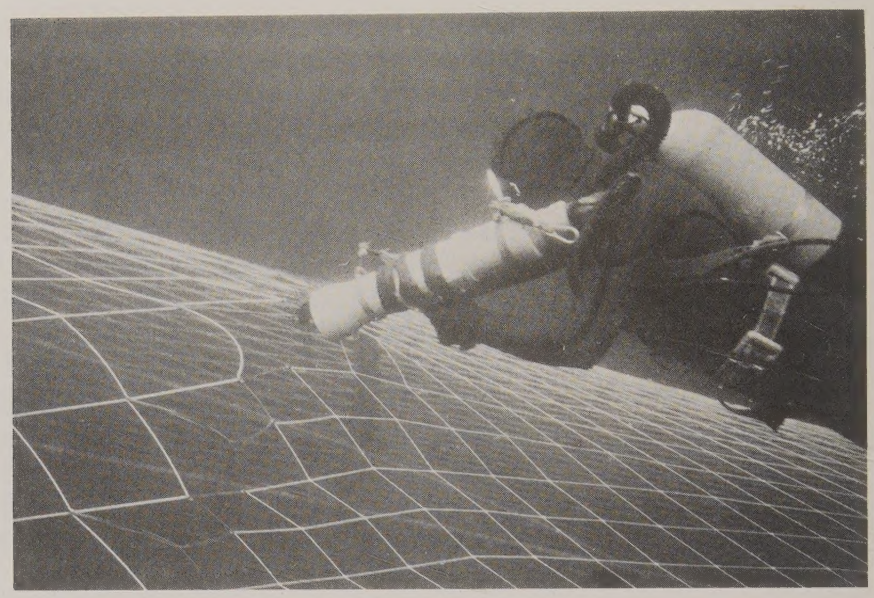


**Plate II.** Free-swimming SCUBA diver with a television camera on the top section of a bottom trawl.

An attempt to construct a two-man, one atmosphere towed vehicle, TUV I, was thought to be a possible solution to the direct observation approach, but this line of development was abandoned at the Marine Laboratory in favour of a small, lightweight, towed wet submersible, TUV II (Plate III). This vehicle carries two SCUBA divers (pilot and observer) utilising a hand-held, low-light-sensitive underwater television camera which can be manoeuvred alongside any part of a fishing gear. This paper describes the vehicle in detail and discusses its various uses and limitations.

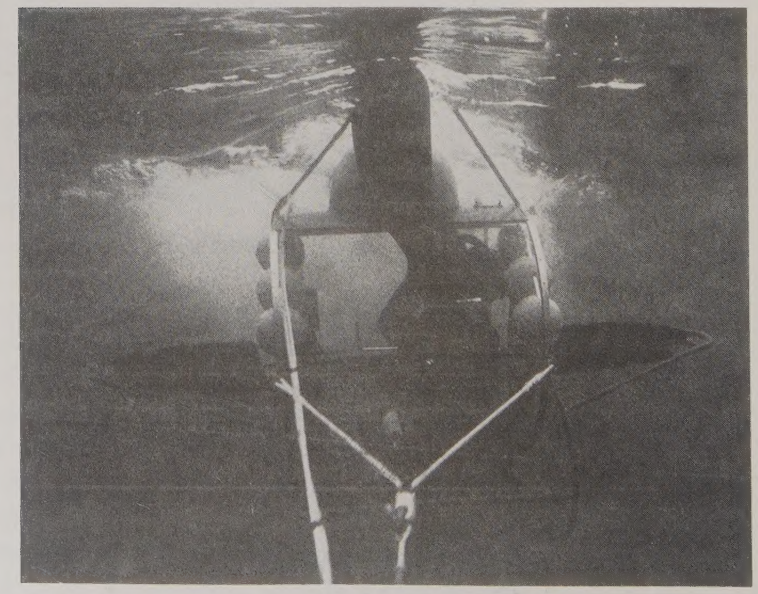


**Plate III.** The Towed Underwater Vehicle, TUV II, just below the surface; the pilot is already in position on the port side.

## Description of the Vehicle

The submersible is partially based on the shape, fin arrangement and buoyancy of a large demersal fish. The steering fins and diving planes are positioned well to the front, with adjustable buoyancy situated high in the vehicle. Figure 1 is an engineering drawing of TUV II giving the main external dimensions and the general description of the components of the vehicle.

A Front rudder
B Air chamber
C Diving plane lock
D Diving plane
E Front rudder control handle
F Diving plane control handle
G Pressure gauge
H Relief valve
I Additional flotation (when required)
J Air control valve
K Front rudder control handle
L Emergency life support system
M Additional flotation (when required)
N Air cylinder
O Relief valve handle
P Towing swivel

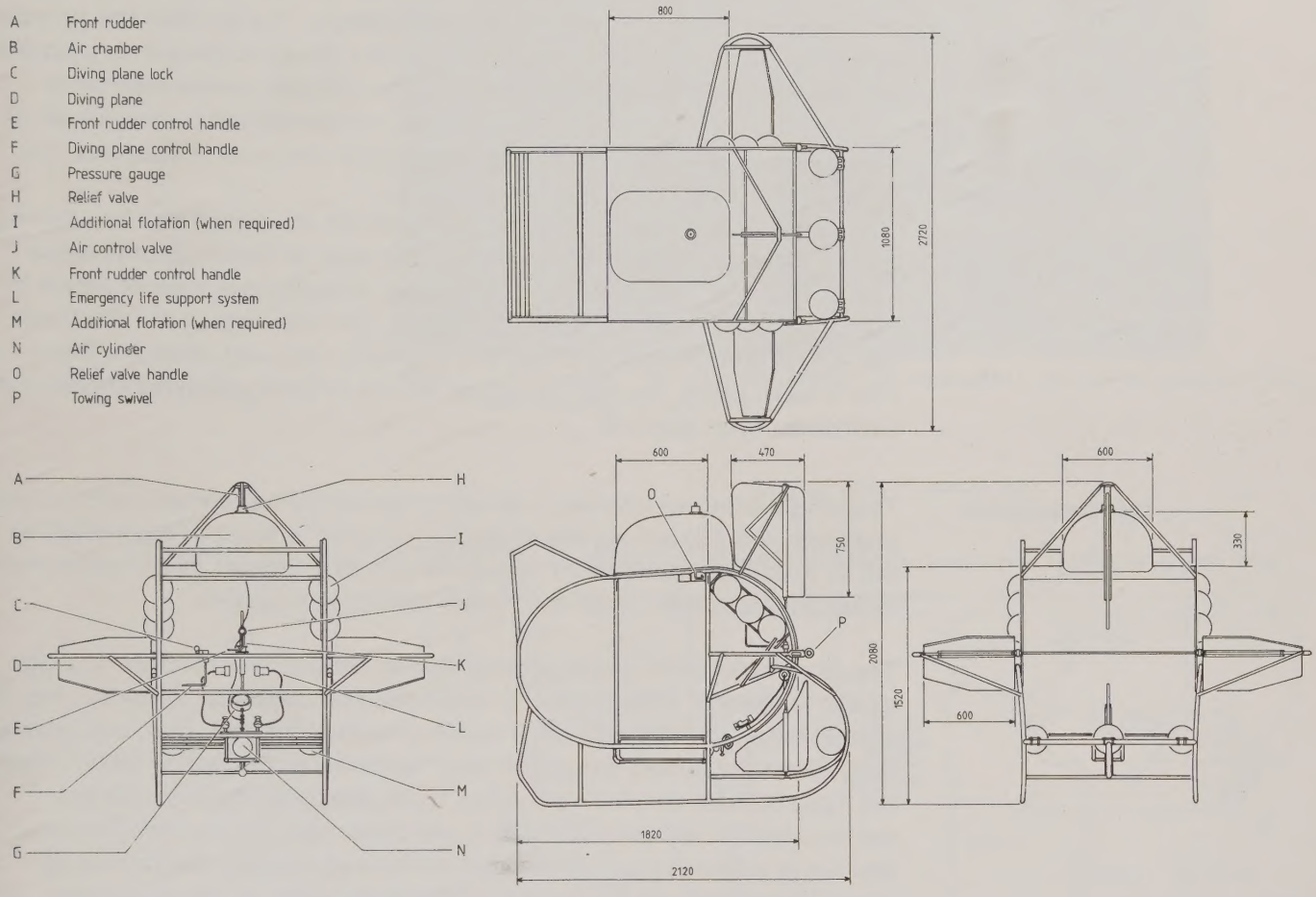



**Figure 1. Plan, front and side elevations of the Towed Underwater Vehicle. All sizes in mm.**

The framework is constructed of 25 mm galvanised conduit tube, with all joints bronze welded. The diving planes and steering fins are made of 13 mm marine plywood, braced with stainless steel straps and supported by 19 mm diameter galvanised conduit tube struts. The control shafts to the steering fins and diving planes are respectively of 16 mm diameter and 13 mm diameter stainless steel rod, and all bushes and bearings are of nylon. The control handles are positioned slightly to the left of centre for the pilot. However, the cameraman can, if required, take over the steering without changing his position. The fibreglass flotation dome is bolted to the roof of the vehicle and sealed with a rubber gasket. A pull handle passes through a 300 mm diameter hole in the base of the dome and operates the air venting valve on top. A 38 mm deep metal skirt is fitted around the hole on the underside of the dome to stop air bubbles from the diver's breathing apparatus entering the chamber and altering the vehicle's buoyancy. Skids of 25 mm diameter galvanised conduit tube fitted to the underside of TUV II protect the lower steering fin from damage on the sea bed and during launch and recovery.

Two 6 mm thick clear acrylic sheets, curved to the required shape, are bolted and strapped to the framework on the front of the vehicle. This screen protects the occupants from the water flow and covers approximately

two-thirds of the lower front but still allows cameras to be pointed downwards and forwards from the underside of the vehicle. The roof of the submersible backwards from the acrylic screen to the start of the tail fins is of 2 mm aluminium sheet. The shaped tail fins are constructed in 6 mm thick acrylic sheet.

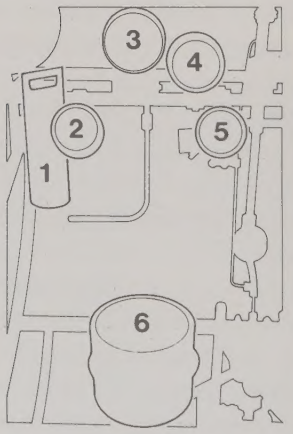
Buoyancy is maintained by using a 2,400 l air cylinder positioned between the divers and clamped on the floor of the vehicle. The air from the cylinder travels via a 6 mm diameter copper pipe to the fibreglass buoyancy chamber and is controlled by a stop valve on line. The cylinder pressure/contents gauge is fitted in front of the pilot. Stability is maintained by careful use of the buoyancy chamber and steering is by manipulation of the control fins.

The submersible is towed from the fishing vessel on a bridle and free-moving shackle by either 18 mm diameter synthetic rope or 8 mm circumference wire. This shackle can slide along the bridle, changing the angle of attack of the towing rope or wire when manoeuvring. The tow rope at the shipboard end is held on the warping barrel, but a winch is required when the 8 mm wire is used. Either method allows the vehicle to be manoeuvred forwards or backwards when required.

## Instrumentation

Two single-hose regulators connected to the vehicle's air supply cylinder are provided with a breathing mouthpiece positioned in front of each diver for use in an emergency. Plate IV shows the port side interior of the vehicle with its various instrument housings in their respective positions.

The communications system (DAFS Marine Laboratory) for diver-to-diver speech consists of cable and bone conduction microphones (Plate IV, Fig. 2), with a completely separate cable system provided for both pilot and observer to speak to the surface controller. This "underwater pluggable" cable system is a Type 322D by Helle Engineering, Dyce, Scotland. Both the surface communication and television cables are taped together at approximately one metre intervals to cause the least amount of snagging during towing. Large "snap-links" are tied to this "TV/comms" cable at approximately 5-10 m intervals and clipped to the towing wire (Plate V) during the launching of the TUV II.




KEY

1 Diver to diver communications unit
2 Time elapsed counter
3 Speed log unit
4 Digital depth gauge
5 Digital temperature gauge
6 Echo sounder

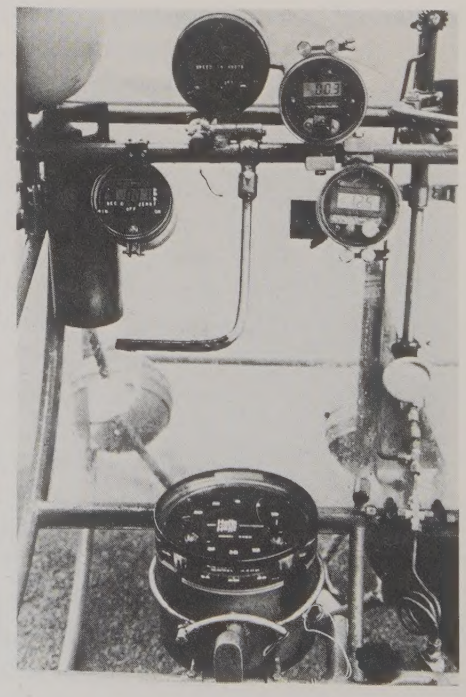


**Plate IV. Port side interior of TUV II, showing the positions of the various instrument and communications systems.**

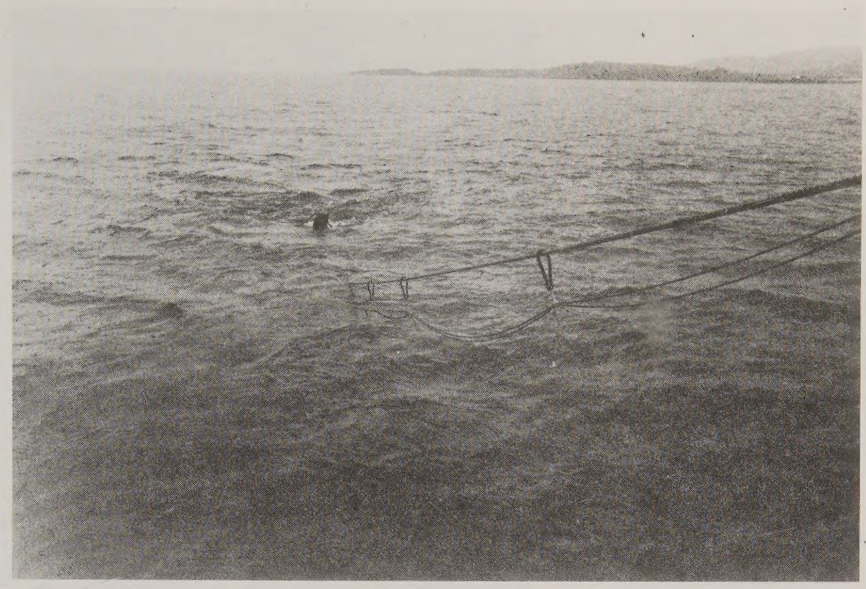


**Plate V. Each "snap link" tied to the "TV/Comms" cable is attached at intervals to the towing wire or rope during launching of TUV II.**

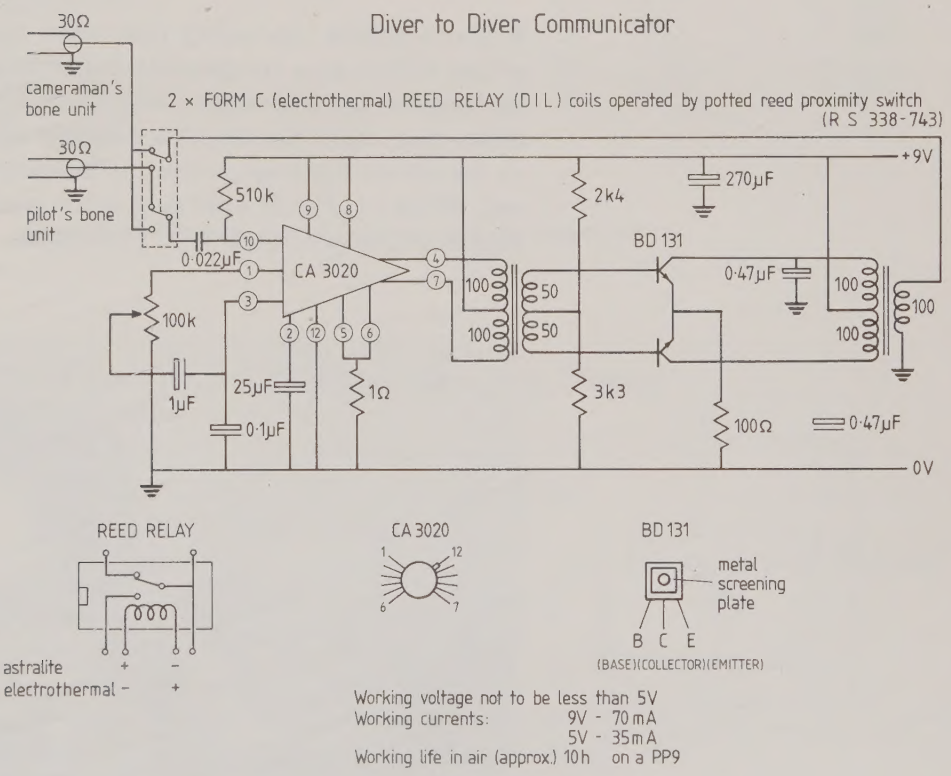



**Figure 2. Circuit diagram of diver to diver communications system used in the TUV II.**

A small lightweight echo sounder (operating frequency 200 kHz) Model 6400, manufactured by Helle Engineering, when fixed in its vertical mode (Plate IV) gives the vehicle's height above the sea bed. However, the instrument can be hand-held horizontally by the observer or pilot (Plate VI) to locate objects under water or obtain linear dimensions of the fishing gear, eg otterboard spread and wing-end spread (Main and Sangster, 1979, 1981a, b, 1982a, b, 1983a, b). A visual LED numerical display on the sounder gives accurate distance readings of echo targets over its maximum range of 110 m (360 ft).

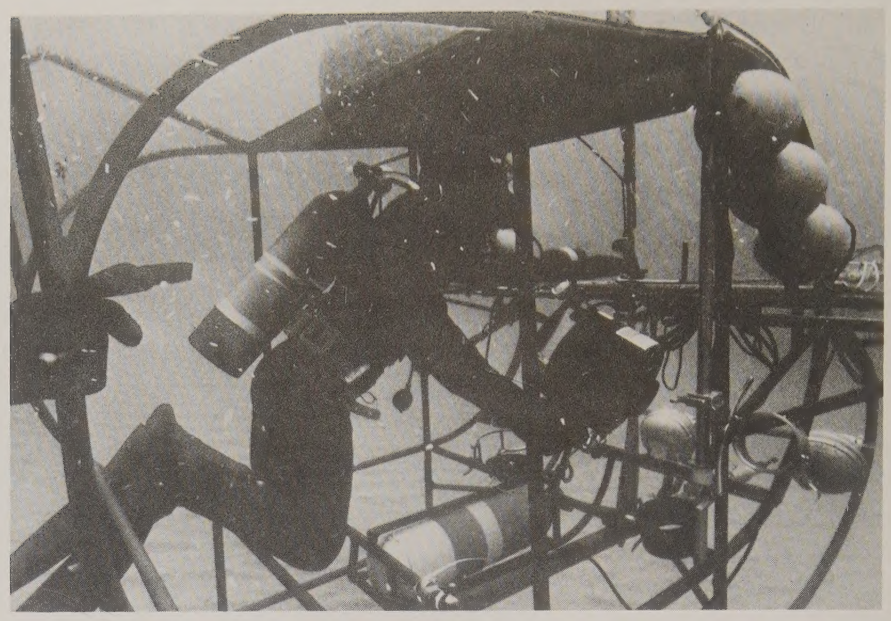


**Plate VI.** **The pilot using the hand-held echo sounder to range and locate an object. (Photograph taken by the observer hanging on to the rear of TUV II.)**

A DAFS Marine Laboratory flow meter type speed log is fixed to the roof of the TUV II on a variable distance sliding rod. The propellor (manufactured by Valeport Developments, Dartmouth, England) can be fixed in position either away from the side of the vehicle during towing (Plate VII) or close to the vehicle body for protection when not in use. The numerical read-out unit (Plate IV, Fig. 3) after calibration is accurate to 0.1 knot over its maximum range of 5.15 m $s^{-1}$ (10 knots).

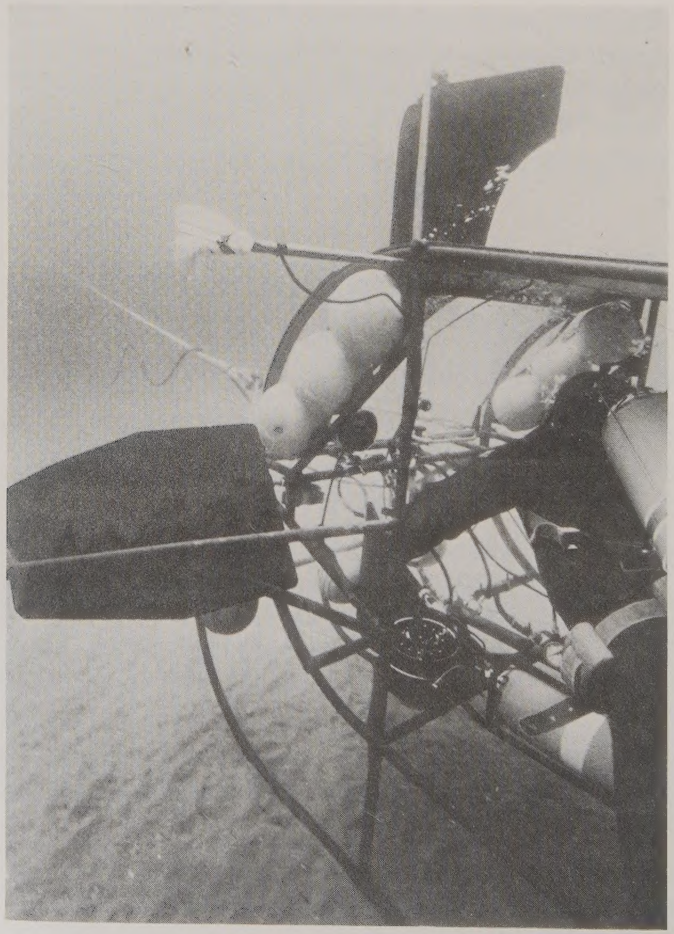
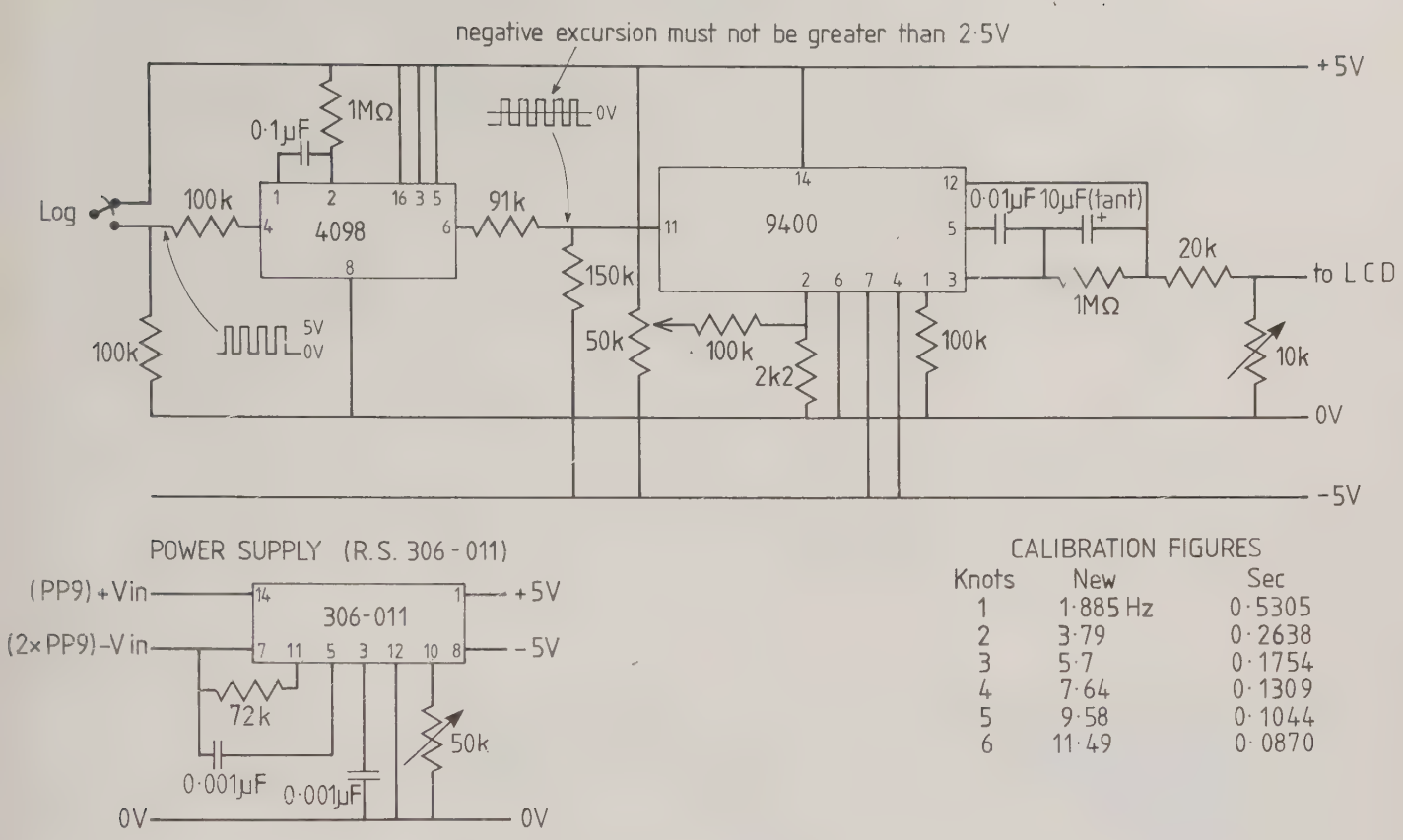


**Plate VII.** **The propellor speed log is fixed on a variable distance sliding rod away from the port side of TUV II during towing. It can be retracted to a position close to the side of the vehicle for protection when not in use.**




CALIBRATION FIGURES

| Knots | New | Sec |
|---|---|---|
| 1 | 1·885 Hz | 0·5305 |
| 2 | 3·79 | 0·2638 |
| 3 | 5·7 | 0·1754 |
| 4 | 7·64 | 0·1309 |
| 5 | 9·58 | 0·1044 |
| 6 | 11·49 | 0·0870 |

**Figure 3. Circuit diagram of the flowmeter speed log readout unit.**

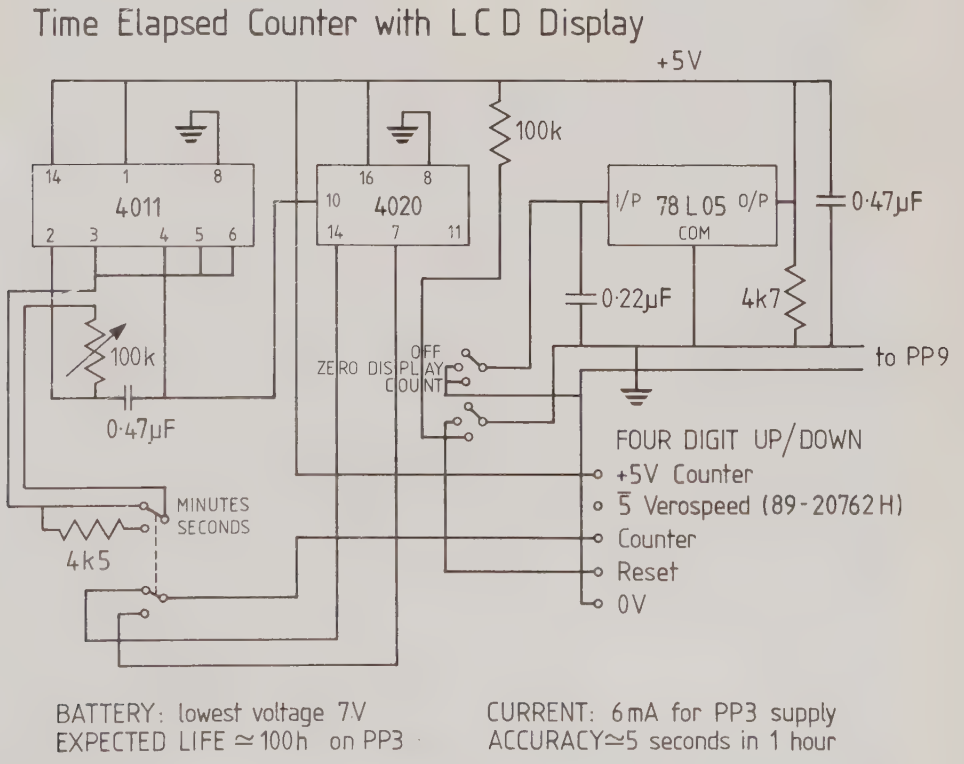



**Figure 4. Circuit diagram of the time elapsed counter.**

A DAFS Marine Laboratory time elapsed counter (Plate IV, Fig. 4) can be set to give digital readings of either the dive time elapsed in minutes from leaving the surface or any time elapsed in seconds.

A DAFS Marine Laboratory depth gauge (Plate IV, Fig. 5) gives the depth of the TUV II below the surface. The pressure transducer (by Druck Ltd, Leicester, England) after calibration is accurate to ± 0.1% over its maximum range of 7 bar.

A DAFS Marine Laboratory temperature gauge (Plate IV, Fig. 6) gives the water temperature in degrees centigrade. The probe (by Lascar Electronics, England) is accurate to 0.5°C over its range -50°C to +150°C.

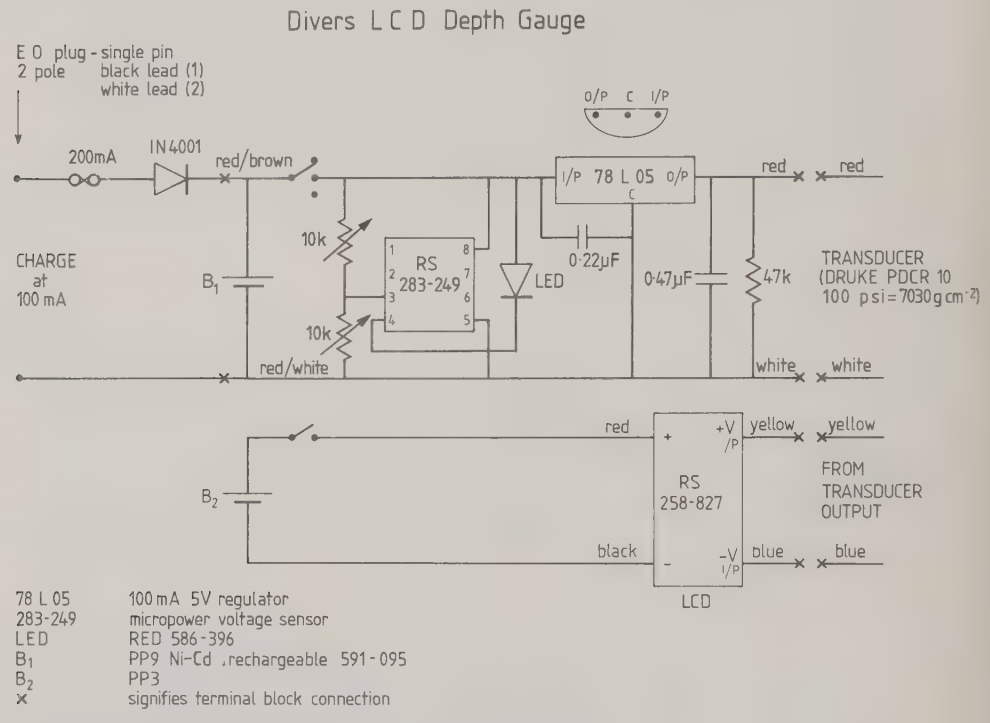



**Figure 5. Circuit diagram of the underwater vehicle's depth gauge.**

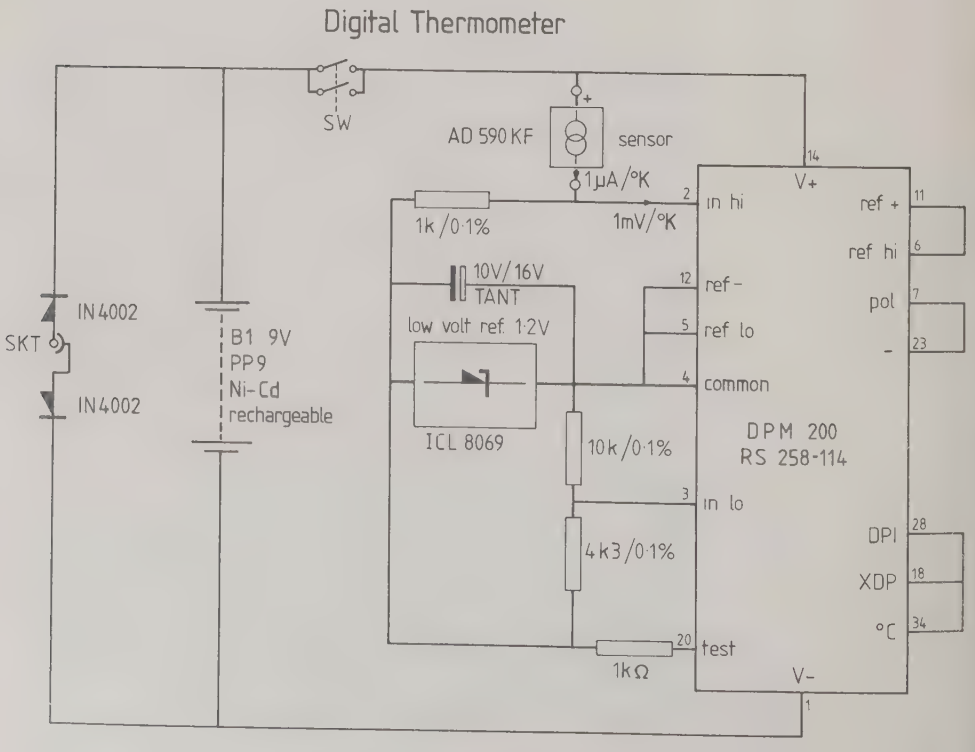



**Figure 6. Circuit diagram of the digital thermometer readout.**

All instrument displays except the echo sounder are digital liquid crystal (LCD) and are positioned in front of the pilot (Plate IV).

A Helle Engineering acoustic pinger (operating frequency 27 Hz) is strapped to the rear of the vehicle for use if the vehicle becomes separated from the towing vessel. The continuous signal emitted from the pinger would enable free-swimming divers to track and retrieve the TUV II by using a hand-held relocation receiver system Type 6270 by Helle Engineering.

Cine or still shot cameras have mountings fitted to the vehicle when required. Plate VIII shows a 16 mm format cine camera on a pan and tilt unit which can be triggered by the pilot when the observer is operating the television camera.

The television camera (RCA Silicon TC-125) is securely held in a multi-position clamp arrangement on the starboard side of the vehicle (Plate IX). The camera can be quickly released from its bracket and held in the diver's hand during filming, or remain fixed in its clamp in a suitable position for continuous TV filming when the observer/diver is otherwise occupied, eg during cine or still shot filming.

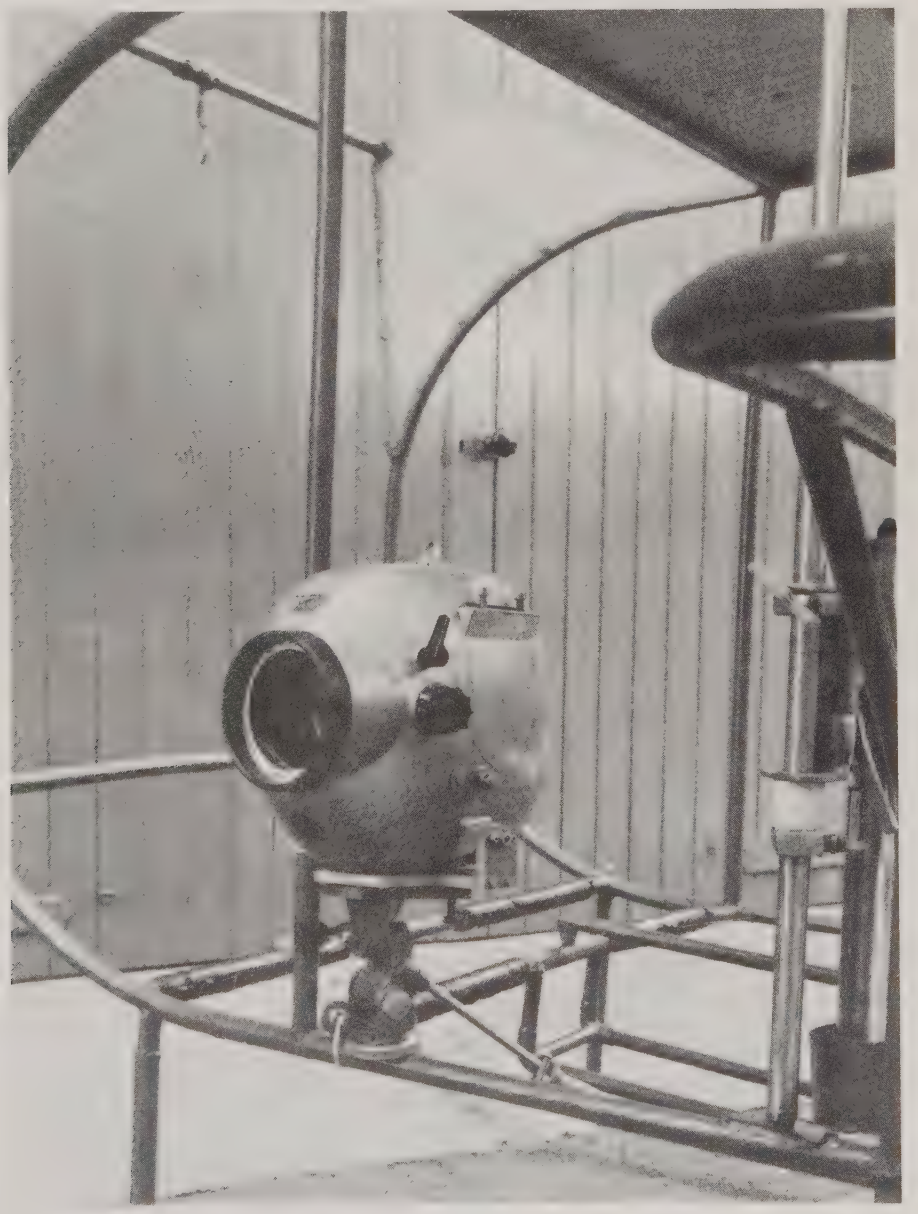


**Plate VIII. 16 mm cine camera in its underwater housing on a multi-position pan and tilt unit.**

**Plate IX** **The television camera can be fixed in its multi-position clamp on the starboard side of the vehicle so that video filming can continue uninterrupted when the observer/cameraman is otherwise occupied.**

Under water lights (VICON/FOTOSUB manufactured by Groove Associates, Hampshire, England) powered by a 30 v DC rechargeable battery supply (DAFS Marine Laboratory) can be fitted to the TUV II when required, either for filming or for general illumination in dark conditions. The power supply will give a bulb output of 375 w for 30 minutes.

**Diving Equipment and Training**

Each diver is equipped with a standard single-hose demand valve fitted with a mouth box (Plate X) manufactured by Sound Wave Systems, California. The microphone and its separate ear piece (manufactured by UDI, Bridge of Don Industrial Estate, Scotland) allows clear voice recording on the sound track of the video tape. The diver's aqualung is a 2,400 l capacity air cylinder fitted with a quick release harness. The "Unisuit" (manufactured by Poseidon, Sweden) a dry, foam-neoprene suit with suit inflation capability is worn over brushed nylon underwear because of the very cold conditions in northern waters.

**Plate X** **The diver's communication microphone is housed inside the mouth-box — a rubber breathing chamber. The ear-piece is held against the side of the head by the rubber mask or mouth-box straps.**

Selection for training with the vehicle is made from the Marine Laboratory fishing gear diving team who are completely familiar with all the free-diving techniques used on nets (Main and Sangster, 1976).

The training in water consists of entering the vehicle on the surface, checking the instruments, communications equipment, air valves and fin movements. The handling techniques of controlling the TUV II at any depth in a stationary mode using the flotation chamber is essential. This is done by venting the chamber via the relief valve and slowly submerging, and then by careful control of the buoyancy chamber holding the vehicle at the desired depth. On satisfactory completion of these tasks, exercises are conducted which require the pilot to dive and hold the vehicle approximately 0.5 m above the sea bed whilst towing at 1 knot; then with the use of the control fins and rudder to move from full left traverse to full right traverse while remaining at a constant 0.5 m from the bottom. As experience is gained, the towing speed is gradually increased to a maximum of 2 m $s^{-1}$ (4 knots). When the pilot achieves satisfactory control of the vehicle at this speed the TUV II is taken to any depth or position required and held there using buoyancy chamber, rudder and diving planes (Plate XI).

**Plate XI** **A competent pilot can submerge the vehicle and hold it under control close to the sea bed at realistic towing speeds (2 m $s^{-1}$). The picture shows a perfect example of this, where TUV II is positioned alongside the port wing of a demersal trawl. The "anti-swivel" device can also be seen just ahead of the towing bridle. The towing cable may spin freely when necessary inside the tube, leaving the electrical cables free from twisting and damage.**

## Operational Techniques

The pre-dive procedures on board ship consist of fitting the instruments, diver to diver communications, and a full buoyancy/emergency air cylinder. The TV camera and the surface communication cable are tested and checked for damage; the buoyancy chamber valves are activated and the towing bridle arrangement and towing warp inspected for damage or deterioration. The vehicle is then held in position near the stern of the towing vessel ready for lowering into the sea.

The fishing grounds used in our experiments are fairly well known and so pre-dive surveys are usually unnecessary. On unfamiliar grounds, however, if doubts arise regarding obstructions such as large boulders or wrecks, echo sounder searches are conducted first. If more detailed knowledge is then required the vehicle is launched and towed over the area to ensure that the grounds are suitable for trawling.

After the vessel has shot its fishing gear and the warps are secure in the towing block, the submersible is launched over the ship's stern without altering towing speed and paid out on its wire (or rope) to the required length with the diving planes fixed in the climb position and the rudder set to full port (ie away from the gear when side trawling). This operation can equally well be conducted from a stern trawler, but in that case the vehicle is launched over the stern of the towing ship between the towing warps with the rudder set to straight ahead. The operation then continues as for side trawling, with the rudder position later being set to full port after the divers enter the TUV II, so that the vehicle is on the port side of the gear on reaching the sea bed.

The area of the trawling gear to be initially examined is decided before launching the vehicle, and the length of towing cable required is fairly accurately known. This length of cable is slowly paid out under slight tension, allowing the water flow on both steering fin surfaces to keep the submerisble on the surface as well as to one side of the ship.

To prevent the possibility of the electrical cable and towing wire twisting together at the shackle and swivel on the towing bridle, an "anti-swivel tube" is fitted over the towing wire as shown in (Plate XI). Basically, this device is a short length of steel tube with a small metal ring welded to the outside surface. If necessary, the towing wire spins freely inside the "anti-swivel tube" and the "snap-links" causing no twist damage to the electrical cables.

When the vehicle is at the required distance astern of the ship, the divers enter the water from a rubber inflatable boat at a position about 20 m in front of the TUV II. The vehicle can be entered at any of the required towing speeds for fishing up to 1.8 m $s^{-1}$ (3½ knots). The divers approach the submersible on opposite sides of the towing wire, each on the side appropriate to his function, pilot or cameraman, and enter from the rear (Plate XII). Checks on all the instruments and communications are then carried out at the surface. On completion of these, the surface controller aboard the towing vessel gives the clearance to submerge, states the bottom depth and starts the stop-watch for the dive time. Only after completion of these check procedures is the vehicle taken to the sea bed, with both divers aware of their "no-decompression" time limit.

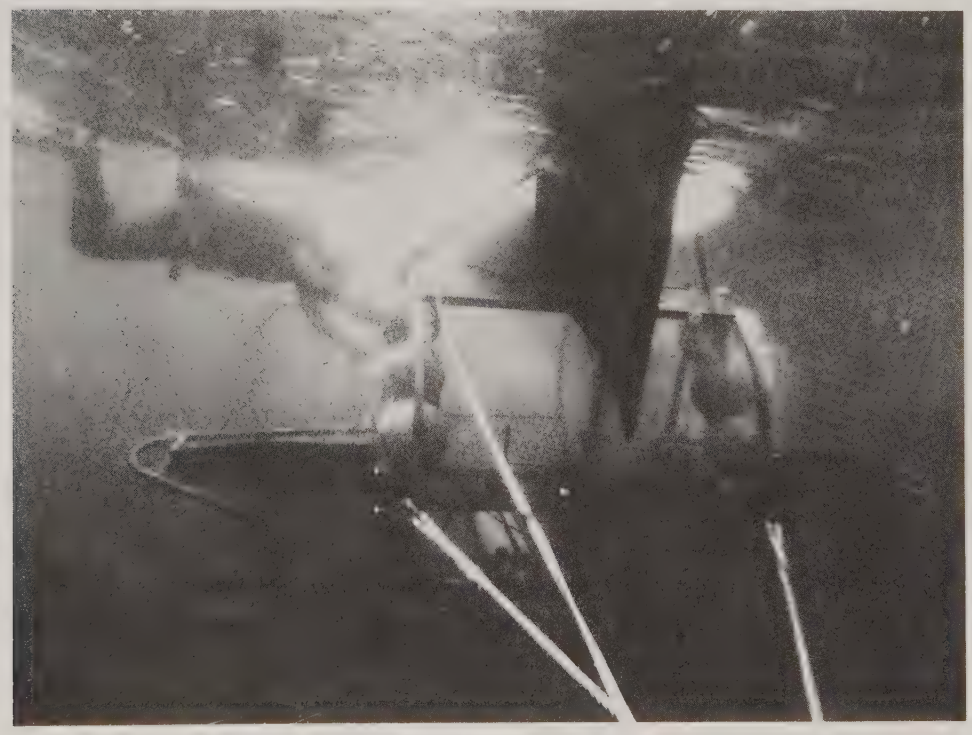


**Plate XII SCUBA diver about to enter TUV II just below the surface.**

A running commentary from the television camera operator commences immediately the TUV II submerges, so that the relevant personnel on the surface ship are aware of what is happening at all times.

As the TUV II approaches the sea bed, the pilot gives full starboard rudder to move the vehicle across to the net. Usually the first indication of the fishing gear is the large sand cloud created by the port side otterboard. The pilot manoeuvres the vehicle over this cloud and takes up a position beside the net (Plate XIII), bridles, or trawl board depending on the predetermined briefing. Usually only a small adjustment of a few metres backwards or forwards on the towing wire is necessary to achieve the best position for observation or filming.

**Plate XIII** **Looking through the front of TUV II's acrylic screen. The pilot has positioned the vehicle in the clear water corridor between the port side sand cloud and the flying wing of the demersal trawl.**

Careful recording of the dive time and depth is maintained by the surface team. At intervals, this is relayed to the divers to give their total time left on the sea bed working to "no decompression limits". The pilot normally keeps an independent check on the dive times from the "time elapsed clock".

The cameraman instructs the surface controller as to when and by how much towing cable is taken in or let out. He also relays to the pilot where to position the vehicle for achieving the best television pictures. The pilot regularly transmits to the surface only the relevant supplementary information (eg speed log or depth gauge readings).

On completion of a dive, the vehicle is brought to the surface using the buoyancy chamber and/or diving planes. The ascent from the sea bed is controlled at the normal rate of 15 m per minute. At the surface both occupants disconnect their communications cables and leave the vehicle with the steering handles locked in the pre-dive position ensuring that neither is fouled by television or electrical cables. They position themselves on the rear of the submersible with their heads above water until the rubber inflatable rescue boat is conveniently positioned for their recovery. The unoccupied vehicle is then winched to the stern of the ship and lifted on board.

## The Effectiveness of TUV II

During the first major exercise with TUV II on a commercial side trawler, eighteen thirty-minute video tapes of unique value were produced from the eighteen daylight dives. No problems were encountered with the launching, warp handling or recovery of the vehicle even though the crew had never handled such a system before and no special research facilities were on board (unpublished results, MV "Arnisdale", June 1976).

Since then, TUV II has completed more than five hundred dives without adverse consequences. Fisheries scientists and gear technologists from various

parts of the world, including England, France, Holland, Norway, West Germany and USA have benefited from the video films and fishing gear measurements taken by the Scottish TUV II diving team during cooperative projects. Plate XIV a to d shows some views taken from the underwater vehicle. Plate XV shows an otterboard striking an oil pipeline. This series of photographs was taken in Trondheim Fjord, Norway in 1978 during an international cooperative project for the oil industry to investigate the effect of trawling gear striking an underwater oil pipeline.

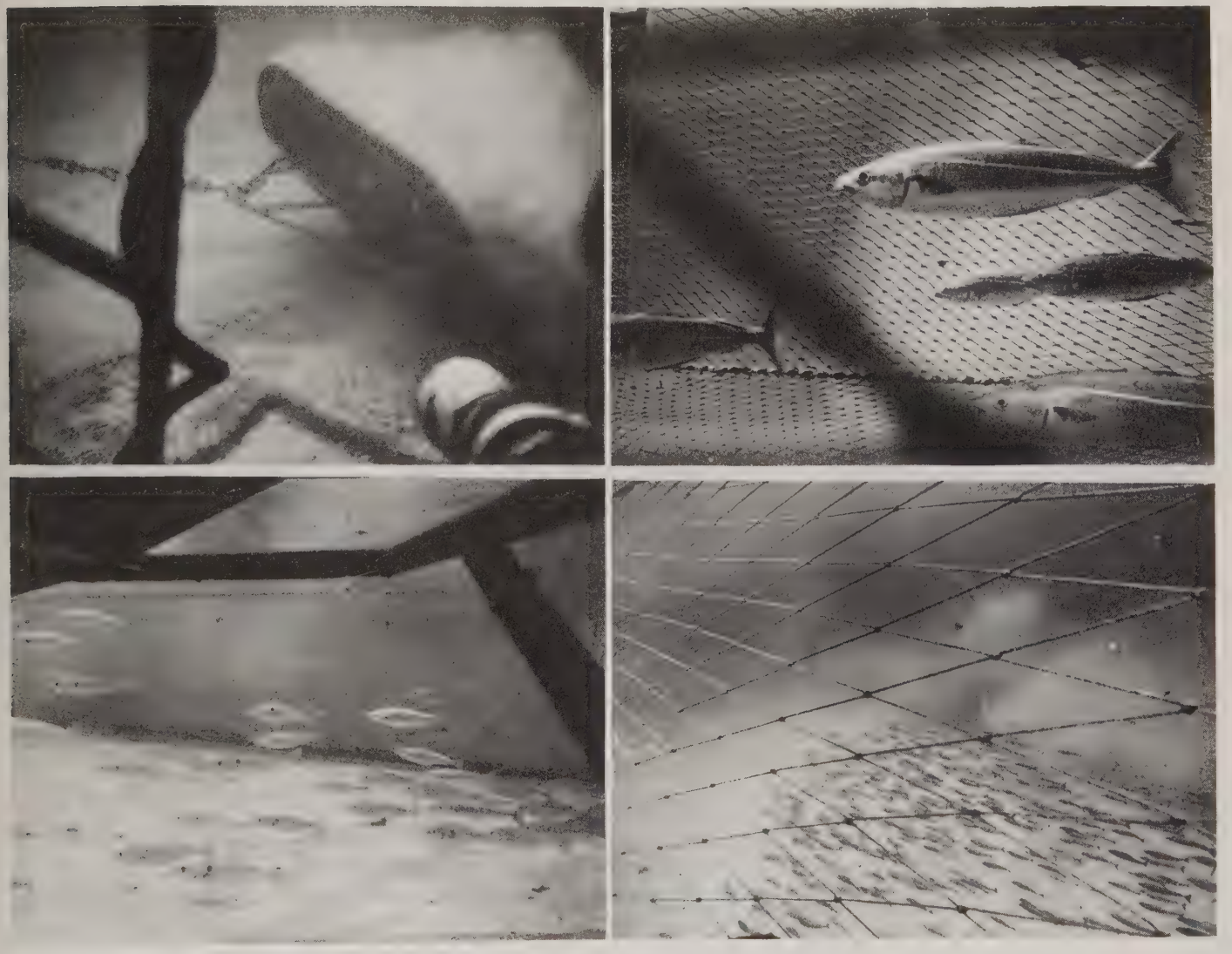


**Plate XIV** (a) **Steel rectangular Vee otterboard (1.7 $m^2$) on a sandy sea bed — towing speed 1.5 m $s^{-1}$, depth 30 m.**
(b) **Shoal of saithe (*Pollachius virens* (L.)) in the funnel of a "Cosalt" 3-bridle trawl. Towing speed 1.5 m $s^{-1}$, depth 25 m.**
(c) **Haddock (*Melanogrammus aeglefinus* (L.)) and saithe swimming between the wings of a Boris 520 Fish/Prawn trawl towing speed 1.5 m $s^{-1}$, depth 25 m.**
(d) **Large shoal of saithe swimming between the wings of a lightly rigged demersal trawl. Towing speed 1.5 m $s^{-1}$, depth 30 m.**

## The Value of TUV II

This type of underwater vehicle does not require an increase in the diving or surface vessel staff. It is robust enough to be handled from both commercial fishing boats and research ships and requires no additional fittings on the towing vessel. It can be moved backwards and forwards from the otterboards, via the bridles, to the net without loss of control or height even if the towing speed is altered. The manoeuvrability of the submersible enables it to swing from one otterboard to the other quickly and smoothly. It can carry two free-swimming divers and an underwater television camera capable of viewing

**Plate XV** **This series of photographs Nos 1-9 (taken from video film) shows a rectangular flat wooden otterboard (6 $m^2$) approaching, striking and eventually lifting over a 0.92 m diameter concrete coated submarine pipeline. Towing speed was 2 m $s^{-1}$, depth 30 m.**

forwards, downwards, sideways and backwards, producing good quality pictures replayable immediately on the fishing vessel. With good communications, commentaries between both divers and surface staff are synchronised and recorded on the video film. The limitation of the system is primarily the relatively short time the divers have in which to make their observations, but well trained operators and a suitable TV camera, backed up by good instrumentation, make the most of these short dives.

## Alternative Uses of the Vehicle

Bottom surveys and searches can be made at a variety of speeds up to 3 m $s^{-1}$ (6 knots), but when an interesting area is encountered the towing speed can be reduced or stopped, and by careful control of the buoyancy chamber the vehicle is kept from dropping onto the sea bed, thus avoiding the danger of damage from rocks or disturbing the sea bed sediment. An advantage of TUV II over other types of towed sledges is that, at the end of a tow or transect, the surface vessel can alter course and come around through 180° and return on a reciprocal course to the previous one. During this manoeuvre the vehicle can be controlled to remain at the required depth and will turn on its own axis without turning over when the strain returns to the towing cable.

Another advantage of this stable platform is its ability to provide observations at speed in mid-water. Plankton samplers and nets can be observed from the start of a tow to completion without the physical strain or the worry of

maintaining position which would be experienced by the free-swimming diving observer. If dye indicator experiments are to be used to demonstrate flow rates through netting panels, this technique can easily be conducted from TUV II and recorded on video tape.

The vehicle can hold its position close to the sea bed and can be manoeuvred quickly to avoid rocks, boulders or deep sand ridges. This is essential when operating close to the sea bed and observing dredges or beam trawls. One of the more important viewing positions when filming the behaviour of dredges from TUV II is from directly in front where the toothed bar can be easily seen raking and lifting scallops, *Pecten maximus* (L.), out of the sea bed sediment.

In strong tideways the TUV II can be taken to various sea bed positions and used as a shelter for the divers, allowing them to work at fixed stations irrespective of the water flow, for example when core sampling or collecting benthic animals. If heavy sampling equipment is required on the sea bed, additional flotation could be attached to the vehicle to compensate for the extra weight and the adjustable buoyancy chamber of the TUV II used for depth control.

**Summary**

A two-man diver-operated towed underwater vehicle is described in detail. The instrumentation housed within the vehicle gives towing speed, depth from the surface, depth above the sea bed, water temperature in degrees centigrade and the elapsed time of the dive in minutes. Both diver occupants can communicate with each other as well as with the surface control team. The vehicle, which is simple to operate and maintain, is ideally suited for launching from most types of fishing vessels to be towed alongside the trawling gear. By using closed-circuit television recording equipment and still-shot and cine cameras, the behaviour of commercial species of fish to a trawl can be recorded *in situ* and studied in detail after completion of each haul. The limitation of this towed vehicle system is primarily the relatively short time in which the divers have to make their observations, but by carefully calculating their diving time to avoid decompressing in the sea, well trained operators can make the most of these short dives.

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